UPDATING FIRE FUEL LOADS AND VEGETATION DATASETS AFTER A NATURAL DISASTER

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INTRODUCTION AND OBJECTIVES:

Over the past decade aerial photography and satellite imagery have improved in spatial resolution, temporally and in affordability to such a degree that small areas can be captured by high resolution sensors, both aerial and satellite. Aerial and satellite imagery, coupled with various remote sensing techniques have allowed for accurate delineations of vegetation communities across a wide variety of landscapes. Recently vegetation maps have been used as a surrogate to create fuel load datasets, particularly in the North Eastern United States. Cross-walking a vegetation dataset to a fuel load dataset is reliable in its resulting classifications, cost effective and extremely fast. Mapping vegetation and estimating fuel loads can be time consuming and arduous process. In addition, it is not uncommon for the mapped area's vegetation and available fuel characteristics to change before the project is complete. Forest succession is a gradual event, and typically one driven by natural stochastic events. Floods and wind events can alter vegetation communities, often in small areas or in a linear fashion. (Greenberg, and McNab, 1998) Occasionally disturbance events occur that affect a larger landscape such as a fire, hurricane or volcanic activity. These events, affecting large spatio-temperal scales, warrant an update of existing vegetation and fuel load datasets. North Carolina State University's Center for Earth Observation has mapped the vegetation and fuel loads of several US National Park Service holdings in the North East Region. Currently, research on methods of updating these datasets is underway in the event that a landscape altering event occurs. Such an event occurred during the overnight hours of September 18-19 in 2003, as the remnants of Hurricane Isabel blew through Petersburg National Battlefield (PETE). In a matter of hours, decades of forest succession had been reset. Fallen deciduous and coniferous trees littered the landscape, forests had become woodlands, and fuelbed characteristics, in both the vertical and horizontal continuum had changed drastically. This project focuses on updating a pre-hurricane vegetation and fuel load dataset through the use of remote sensing techniques, specifically an object oriented classifier, Visual Learning System's Feature Analyst. Creation of vegetation and fuel load datasets is a laborious process that takes years to complete. Events, like hurricanes resulting in the widespread damage like that seen at PETE rarely occur, but when they do occur, they greatly alter the natural environment. PETE was not established for its scenic views or unique vegetation but it offers the citizens of Petersburg with unparalleled recreation opportunities. PETE is located within the Wildland Urban Interface and because of this, it is imperative that PETE has adequate and accurate spatial fuelbed data, not only allowing park managers to make educated and proper land management decisions but to inform local agencies of possible hazards as well. Presented in this paper are the cost- and time-efficient methods of updating PETE's fuel load datasets and the results of this undertaking.

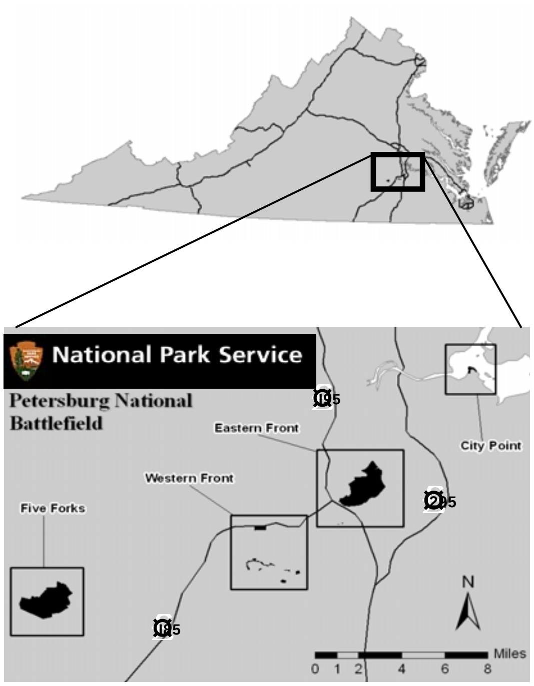

Fig. 1. Location of Petersburg National Battlefield.

METHODS:

Analysis - While all vegetation communities suffered damage caused by Hurricane Isabel, areas consisting primarily of deciduous forests bore most of the damage. The magnitude of the hurricane's effect was immediately realized and park managers decided to document the scope of destruction via remote sensing techniques. Digital aerial photography was chosen because of its ability to capture the area of interest at a small scale (1:6000) and at an affordable cost. True Color and Color Infrared (CIR) imagery were captured in October of 2003, processed and delivered to North Carolina State University's Center for Earth Observation in the summer of 2004. Upon initial visual inspection of the imagery, areas of downed woody debris were easily identified. Applying traditional techniques of supervised and unsupervised classification, further areas of forest damage were identified. However, it became apparent that spectral responses alone could not quantify all areas of forest damage. Classifying the imagery based on Leaf Area Index or NDVI classification led to similar inconclusive results. The inability to quantify the amount of woody debris present did not satisfy the objectives of the project and required a different approach. Isolating spectral responses, within the areas of forest damage, did not lead to a definitive classification of downed woody debris. All of these traditional remote sensing methods rely upon spectral information in an image while neglecting the spatial arrangement of pixels. Literature reviews (O'Brien 2003 and Vanderzanden 2003) pointed to the use of automated feature extraction or object-oriented classifiers. Descriptions and reviews of VLS Feature Analyst's requirements, methods of object extraction and output into a Geographic Information System (GIS) format, matched the requirements and desired products for the scope of work to be completed at PETE.

Remote sensing – The focus of automated feature extraction is the recognition of spatial patterns of pixels in addition to the grouping of spectral responses of those pixels. Classification based solely on spectral responses of pixels does not take advantage of the benefit that high resolution imagery provides. Determination of the more appropriate type of imagery was made first. The true color and CIR imagery taken of Fort Gregg and surrounding area was used to determine Feature Analyst's (FA) ability to indicate areas of downed woody debris. Training sites or areas of interest were drawn around areas of downed woody debris and in some instances a single downed tree. Unlike a "wall-to-wall classification" trainings sites of only downed woody debris were established. Using these areas as training sites, FA mapped areas that met similar spectral and spatial pattern responses. As an iterative, or hierarchal process, FA outputs are analyzed after each run, with adjustments made to the output shapefile to indicate areas that were identified correctly and areas identified incorrectly. This "on the fly" adjustment allowed the training sites to improve with each iteration. Iterations were performed until the user felt all areas of downed woody debris had been mapped. The same process was then applied using the CIR imagery, utilizing the same shapefile of trainings sites. The resulting classifications were compared for areas of similarity and differences. After careful examination the true color imagery was chosen based on its ability to discern downed woody debris sites accurately, especially in areas of dead herbaceous matter or bare earth. In addition, when using the CIR image, FA confused roads and portions of homes (both of linear pattern) with downed woody debris more often than when using the true color image. As a result it took more time and iterations to arrive at an acceptable level of classification.

The Eastern Front, because of its size and extent of damage took the longest to classify. The species makeup of forests of the Eastern Front is different from other areas of the park, in that both plantation and naturally occurring pine are found. FA classification outputs were more accurate if training sites were created for each general class (i.e., pine and hardwood). (In the imagery, pine trees are small in size and typically black in color while deciduous trees are larger and either white or brown in color.) When training sites of both tree types were created, the resulting output contained more clutter and took longer to differentiate correct areas from incorrect areas. When training sites of each type were created, the resulting classification was less cluttered and more accurate. This resulted in fewer iterations and the classification of downed woody debris at a faster rate. When clutter, from both output classifications had been effectively removed the outputs were merged, resulting in one layer of mapped downed woody debris. With all occurrences of downed woody debris mapped, quantifying the damage began by creating affected area polygons.

Establishing training sites to enable FA to successfully classify an image was a time consuming process. However, this process did not require the knowledge or understanding of spectral characteristics of specific features, like dead woody material. While successfully applying FA required training time, this investment in time was far less than that required to classify an image based solely on spectral responses.

Quantifying areas of damage was accomplished by establishing generalized areas of forest damage then determining the degree or amount of damage per area. Converting a vector image representing downed woody debris to a raster image then reclassifying the raster image into two categories created areas of forest damage. This approach allowed for the capture of fine fuels that are important to fire spread but hard to capture using remote sensing. Using the line density function in ArcMap a buffer determined by the frequency of lines was created. The resulting raster image was classified into two categories, based on a break point set at .01 or 4.4%. This mimicked a minimum density requirement with the raster image indicating the presence or absence of downed woody debris. Other break points were applied, but were either to restrictive, excluding areas of previously mapped downed woody debris, or too general, including areas clearly not damaged. This generalization of forest damage allowed the polygons, representing downed woody debris to 1) capture 1- and 10-hour fuels missed by FA classifications and 2) capture the horizontal spatial distribution of downed woody debris across the landscape. These polygons were quantified based on their percent coverage of downed woody debris. The area of each polygon representing an individual occurrence of downed woody debris was calculated, summed, and then divided by the area of the generalized forest damage polygon in which it was located. FA was invaluable in indicating downed woody debris in a timely fashion and enabling a user to create generalized areas of forest damage with which a quantifiable map could be made.

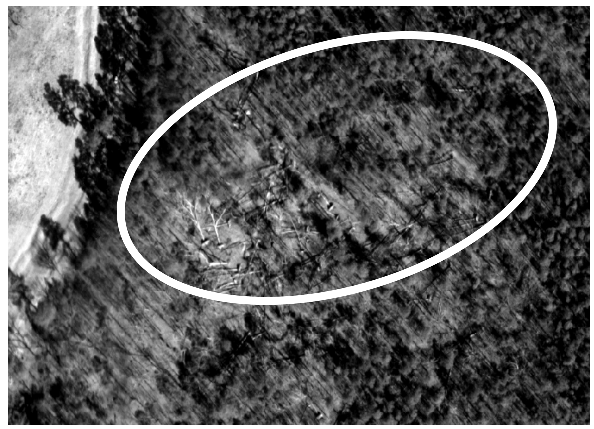

Fig. 2. Area of downed woody debris in PETE.

Ground Truth – Assessing the validity of the FA classifications was done according to Brown's Transect guidelines and Burgan Rothermal Protocols. Field work addressed two questions: 1) the ability of FA to identify downed woody debris, and 2) determine if the percent coverage classification method accurately represented the actual fuel loads present in the forest damage areas. Using Hawth's Analysis Tools random point generator, points were distributed in areas classified as damaged and undamaged (but within PETE boundaries). At each sample point any occurrence of downed woody debris within four meters and longer than two meters in length and 12 inches in diameter were recorded as downed woody debris. 100% of points placed in areas called damaged had downed woody debris in them and 90% of points placed in not damaged, had no damage. These results may be inflated by the copious amounts of downed woody debris due to several ice storms over the past decade, particularly a 1998 event. It was not possible to definitively determine which event, ice storm or hurricane caused the forest damage. With the mapped areas of downed woody debris, as indicated by FA, validated, the second objective of the field work, fuel load measurements, was begun. Using Hawth's Analysis Tools random point generator, several points were placed in each polygon (51) that met the minimum 0.5 acre mapping unit for this project. These points would serve as possible plot locations. To ensure that an entire plot would fall within the forest damage polygon, a 50 foot buffer was placed around each point to determine the point(s) that would meet the required transect length. If the buffer extended beyond the damage polygon then the buffer and corresponding point were eliminated as a possible plot location. Once all possible plot locations were determined they were stratified based on their attributes, percent cover, pre-hurricane fuel model, and vegetation type.

Closely adhering to Brown's Transect guidelines, (Brown, 1974) (modifications to Brown's Transect guidelines will be discussed later) fire fuel load measurements were taken. Fifty-foot transects were placed in the northerly and easterly directions in order to characterize the woody and herbaceous vegetation present, as well as the fuels. Fuels represent the dead and alive organic matter available for fire ignition and spread.

Fuels are characterized by their load (weight per area), size (1-, 10-, 100- and 1000 hour), and bulk density (weight per volume). To adequately capture these characteristics several measurements are made at each plot. Duff and litter depth measurements were taken at the one foot mark and repeated at the 5, 10, 15, 20, 25, 30, 35, 40 and 45 foot mark. The duff layer was measured from the base of the litter layer to the top of the mineral soil. Leaves, pinecones, bark, and dead grass were considered litter. Grass overlying slash or other woody debris was not considered in the measuring of litter. Fuel load measurements were made from the 0-6 ft mark, 6-12 ft mark, and 12-50 ft mark of each transect. Woody debris was classified as, 1- (0-0.25 in), 10- (0.25-1 in), 100- (1-3 in), and 1000 (3+ inches) hour fuels and were counted from the ground surface to a height of 2 meters. Included in the tally were woody debris from partially uprooted trees. This is a modification to Brown's Transect guidelines, which calls for the counting and measuring of woody debris that is detached from the origin of growth. That is if a tree is blown over or knocked over by another tree and a portion or the entire root ball remains in the ground, it is not considered as downed woody debris. This stipulation was not followed in this study because of numerous trees that were dead but still attached to their origin of growth. If a tree, crossing either transect below two meters, was attached at its origin of growth and exhibited any semblance of growth, it was not included in the tally. At the time of field measurement (March 2005) the toppled trees had had one growing season and were entering their second. In one growing season a tree can adjust to various adverse growing conditions. (Whigham, D 1991) If any indication of this was noted, (e.g., change of direction in branch growth or presence of buds) the tree was not counted. While not affecting the tally of 1- or 10-hour fuels, this modification increased the tally of 100- and 1000-hour fuels, and better represented the existing and future fuel load of the plot. Burgan and Rothermel Protocols (Burgan and Rothermel 1984) were followed to more accurately characterize the plot's vegetation in terms of a qualitative measure of the litter, grasses, shrubs, and trees present. Grass, shrub and tree species, if applicable were identified, with the tallest occurrence of each measured. Percent coverage of the plot, by litter, grass, and shrub were measured. Type of litter was recorded as well. If coniferous litter was present then needle length was measured. A percentage of the litter load in each class (1-, 10-, and 100-hour) of the plot was estimated as well. Litter compactness was measured to further document the landscape as it is important in determining the rate of fire spread. In total 24 plots, each requiring from 1 to 2 hours to complete, were measured. This process was time consuming but necessary to record all required data and evaluate the classifications done by FA, in order to accurately update the existing fuel load datasets.

RESULTS:

Through data manipulation in a GIS and ground observations, an analysis of the damaged areas exhibited no discernable spatial pattern. Damage incurred was not restricted to one type of vegetation formation. The type of damage varied widely as well, from complete uprooting and snapping of boles to minor crown damage. The only noticeable pattern was the direction that the trees were laying on the ground. Most uprooted trees fell to the ground with their crowns to the west of their associated root ball, as the hurricane winds were from the northeast.

FA excelled in its ability to map areas of downed woody debris. The resulting classifications were more accurate in hardwood canopy cover than in mixed or coniferous cover. While plot points were partially determined on their percent coverage, this had no bearing upon the assigned fuel model. Fuel loads (and thus fuel models) were determined from plot measurement calculations coupled with comparing written descriptions of fuel models to observations made.

To further characterize the FA classifications, the perimeter of an affected area was measured and compared to that of the area indicated by FA. The goal was to gauge the effectiveness of the generalization method used to capture missed areas, consisting of one and ten hour fuels. The accuracy of FA-classified areas was directly related to canopy type. Perimeters of forest damage were captured more accurately in areas of hardwood canopy dominance than in areas of mixed or coniferous cover. This lower accuracy in coniferous formations is related to FA's inability to locate woody debris occurring under the canopy. Where canopy gaps occurred in these

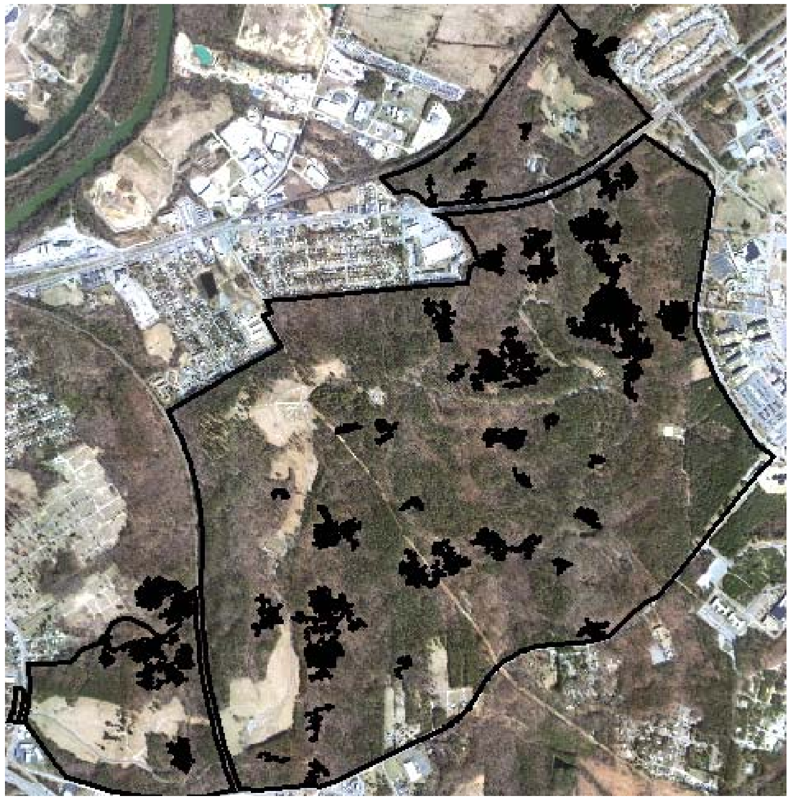

Fig. 3. Feature Analyst mapped areas of downed woody debris in the Eastern Front of PETE.

formations, FA mapped any occurrence of downed woody debris. For this project the use of leaf-off photography was imperative, as this allows for the capture of downed woody debris which would have been obscured if leaf-on photography had been used.

While mapping the occurrences and the spatial distribution of downed woody debris was successful, quantifying those areas was not at least through using remote sensing techniques. Fuel load calculations were made using Brown's Transect Guidelines. These calculations, in combination with professional opinion (Klein, 2005), and written descriptions of the Anderson fuel models, were used to assign new fuel models to the affected areas. Taking into account the entire landscape where areas of forest damage occurred, (i.e., pockets of severe fuel loading found in an area of otherwise uniform fuel load) the fuel model 10 was assigned to all affected areas, except in an area of younger homogenous pine, where "red slash" and grasses were documented. This area was assigned to fuel model 11.

The inability to quantify the downed woody debris should not overshadow the time and money saved by using FA. Time required to complete field work to determine appropriate fuel loads, was reduced from months to a week. By focusing attention to specific areas of PETE, field work was done in areas that were known to have an increase in fuel loads. As part of the Wildland Urban Interface this quick assessment and inventory of the available fuel is a useful hazard identification tool for local land managers. Using FA to map areas of downed woody debris in larger and more remote settings would significantly reduce the time and money needed to update fuel load datasets.

The second objective of this project was to update the vegetation dataset of PETE. This was done by processing all associated data (pre-existing vegetation and mapped FA forest damage) into a GIS and performing an overlay process. In most areas the original vegetation formation code was kept but changes to the formation code occurred in areas affected by the Southern Pine Beetle, not the hurricane. In the northern portion of the Eastern Front of PETE an area previously called formation code I.C.3.N.a (mixed forest) was changed to I.B.2.N.a (deciduous forest). In smaller areas throughout the park portions of formation I.A.8.N.b (coniferous forest) were changed to I.C.3.N.b (mixed forest). According to the National Vegetation Classification System (NVCS) areas where canopy coverage is less than 60% are to be classified as a Woodland type. However, a Woodland ecosystem is established in part because of other environmental gradients such as soil depth, type and precipitation; they are not established as a result of insect infestation or storm damage, (unless the overstory and understory compositions change). In PETE's case a forest suffered extensive and severe damage that created large canopy gaps but these areas will continue succession back towards a forest climax.

CONCLUSIONS:

Remote sensing, specifically automated feature extraction is an excellent tool to use for mapping areas of woody debris. Accurate and current data is vital to communities along the Wildland Urban Interface. The ability to accurately classify woody debris allows land managers to concentrate their scarce funds, time, and efforts toward affected areas. Unfortunately, quantifying these areas of woody debris remains a laborious and time consuming process but with the help of Feature Analyst, the areas where increased fuel loading occurs are delineated quicker. The reduced field work allows time and money to be allocated to other projects. Future work will involve testing the applicability of Feature Analyst's learning file in other areas of PETE, such as the Five Forks section. The learning file should allow a user to transfer a classification methodology from one project to another, thus reducing the time needed to train the software, to locate downed woody debris. Subsequent projects will look at mapping canopy gaps that occur after hurricanes or other wind-driven events occur. This will be particularly helpful in areas dominated by coniferous canopy cover. As high resolution imagery becomes readily available, automated feature extraction will enable researchers to reliably delineate features on the ground, thus increasing the range of remote sensing applications.

REFERENCES

Anderson, H.E. 1982. Aids to Determining Fuel Loads for Estimating Fire Behavior. USDA Forest Service GTR-INT-122. Intermountain Forest and Range Experiment Station, Ogden UT.

Brown, J.K. 1974. Handbook for Inventorying Downed Woody Material. USDA Forest Service, GRTE-INT-16., Ogden, UT.

Burgan, R.E. Rothermel, R.C. 1984. Behave: fire behavior prediction and fuel modeling system-FUEL subsystem. USDA Forest Service GTR-INT-167., Intermountain Research Station. Odgen, UT.

Frost, Cecil C. 1998 Presettlement fire regimes of the United States: a first approximation. Pages 70-81 in Theresa L. Pruden and Leonard A. Brennan (eds.). Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20. Tall Timbers Research Station, Tallahassee, Fl.

Greenberg, C.H., and W.H. McNab. 1998, Forest disturbance in hurricane-related downbursts in the Appalachian mountains of North Carolina: Forest Ecology and Management. 104 170-191.

Millinor, William A. 2000. Digital vegetation delineation on scanned orthorectified aerial photography of Petersburg National Battlefield. Master's Thesis, North Carolina State University.

O'Brien, M.A., 2003. Feature Extraction with the VLS Feature Analyst System, Proceedings of the American Society for Photogrammetry and Remote Sensing. NIMA/IDR, Reston, VA.

Klein, Robert. Fire Ecologist, Great Smoky Mountains National Park, email. April 15, 2005.

Sandberg, D.V, R.D.Ottmar and G.H. Cushion. 2001. Characterizing fuels in the 21st Century. International Journal of Wildland Fire 10:381-387.

Smith, Mark P., 2003. Predicting Fuel Models and Subsequent Fire Behavior from Vegetation Classification Maps. Master's Thesis, North Carolina State University.

Vanderzanden, D. and M. Morrison, 2003. High Resolution Image Classification: A Forest Service Test of Visual Learning System's Feature Analyst. Remote Sensing Applications Center, Salt Lake City, UT.

Whigham, D, I. Olmstead, E.Cano, and M. Harmon. 1991. The impact of Hurricane Gilbert on trees, litterfall, and woody debris in a dry tropical forest in Northeastern Yucatan Peninisula. Biotropica 23:434-441.